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(71) Applicant: AIRTRONIC, INC. [US/US]; 9615 Inter Ocean Drive, Cincinnati, OH 45246 (US).

(72) Inventors: FREYTAG, David, C.; 2121 Alpine Place, Cincinnati, OH 45206 (US). FREYTAG, Gary, M.; 702 Shakertown Court, Cincinnati, OH 45242 (US).

(74) Agents: POFFENBERGER, John, D. et al.; Wood, Herron & Evans, 2700 Carew Tower, Cincinnati, OH 45202 (US).

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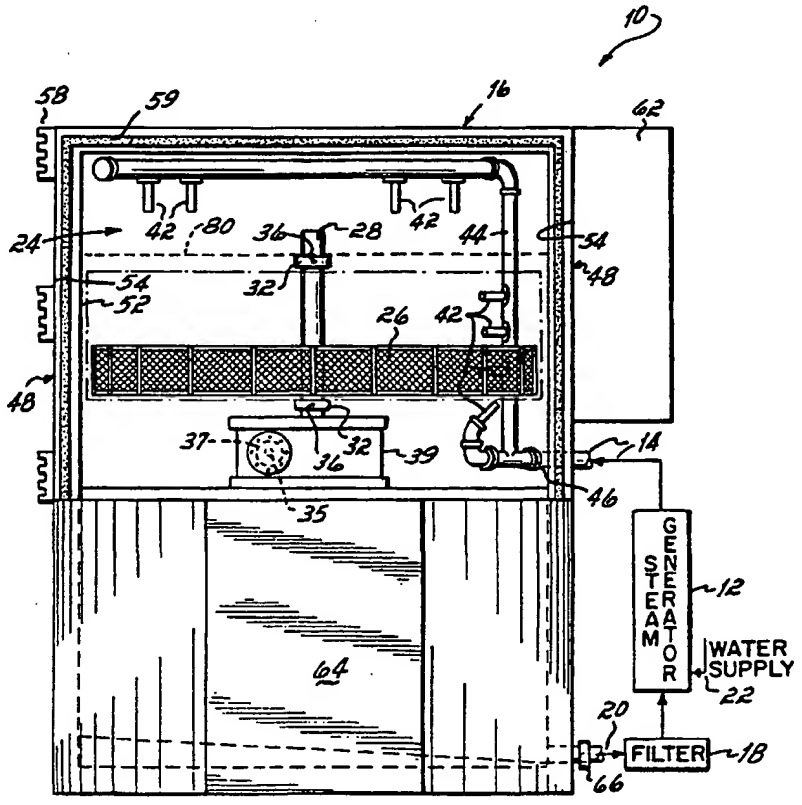
(54) Title: INDUSTRIAL PARTS CLEANING SYSTEM

(57) Abstract

An industrial parts cleaning system (10) injects superheated water under pressure into a wash cabinet (16). Contaminated industrial parts (38) which include intricate orifices, internal passages, and complex geometries are mounted in a rotationally driven wash basket (26) within a cleaning compartment (24) of the wash cabinet (16). The superheated and pressurized water is released through a pattern of specially designed stepped expansion nozzles (42). The nozzles (42) disburse the superheated water with controlled vaporization to create high velocity droplets impinging upon the contaminated parts. The high velocity water droplets provide an invasive high temperature cleaning action requiring no additional cleaning chemicals or detergents. The system is particularly advantageous for cleaning oil based dye penetrants, waxes, and machining oils from complex geometry industrial parts. The system (10) includes a filter (18) for the economical recycling of the water to be returned to a remote modulating burner steam generator (12).



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# INDUSTRIAL PARTS CLEANING SYSTEM

## BACKGROUND OF THE INVENTION

This invention relates to a system for cleaning. More particularly, it relates to a system for using superheated water and steam to remove specific contaminates from industrial parts, specifically those parts having intricate orifices and internal passages.

When industrial parts are manufactured by a laser drilling process, they are commonly coated with a vegetable wax during the production process. The laser drilling process is beneficial in manufacturing industrial parts with complex geometries which include intricate orifices and internal passages interconnecting the orifices. For example, airfoils and other components in aircraft jet engines have such complex geometries as disclosed in U.S. Patent Nos. 4,762,464 and 4,808,785. The wax is used to block specific passages and orifices in the part in order to more accurately shape and form the part without inadvertently laser drilling unwanted holes not required by the specifications. As a result, deposits of wax on the industrial

parts are embedded within these openings, orifices, and passages. Additionally, the wax accumulates on the external surface of the parts.

These industrial parts must be cleaned both prior to and after the inspection and ultimate use of these parts. The wax must be removed form both the external surfaces and the accumulated or embedded wax within the orifices and internal passages of the parts. The cleaning requirements for such parts is very demanding according to industry standards.

Similarly, industrial parts are often machined into complex geometries with internal passages and intricate orifices. During the machining process, the parts become contaminated with oil and other lubricants. As part of the quality control of the machined parts, an inspection technique is commonly utilized which includes coating the parts with an oil-based fluorescent dye penetrant. The oil-based dye penetrant is applied to the industrial part such that the orifices or internal passages are also covered. An emulsifier is also applied to the machined part during the inspection process.

The industrial part is inspected under a black light to illuminate any minute cracks, imperfections, or faults into which the dye penetrant has embedded. However, both before and after the black light inspection, the machined part must be completely cleaned in order to remove any machining oil or other contaminant prior to the inspection and the dye penetrant and other residual chemicals must

be removed after the inspection. This inspection technique is also commonly used on aircraft engine parts with multiple minute orifices leading to serpentine internal passages as described in U.S. Patent Nos. 4,762,464 and 4,808,785.

One prior solution for cleaning complex machined or laser drilled industrial parts contaminated with machining oil, oil-based dye penetrants, wax, and other contaminants is vapor degreasing. Vapor degreasing methods use chemical solvents such as trichloroethylene to remove the contaminants by exposing the parts to vapors of the chemical solvents. Although vapor degreasing has proven to be effective in removing the contaminants from the parts, it is very expensive. The high cost of vapor degreasing is due to the ever increasing cost of the chemicals such as trichloroethylene, the requirements for the environmentally safe disposal of the expended chemicals, and the cleaning of the vapor degreasing system itself. Regulations which are intended to reduce the use of toxic chemicals and to ensure the proper disposal of such waste lead to the increased cost of cleaning industrial parts by vapor degreasing.

Another prior solution for the cleaning of machined, laser drilled and other industrial parts is aqueous parts washers. Aqueous parts washers repeatedly wash the parts with combinations of water, soaps and detergents. However, even after washing and rinsing the contaminated parts in aqueous parts washers, the parts are often still contaminated with the oil-based dye penetrants and waxes. The

internal passages and intricate orifices are particularly difficult to clean using only detergents, soaps and water especially when contaminated with oils and waxes. Furthermore, the soaps and detergents become ineffective after extended use and must be replaced. Likewise, the waste wash water containing the detergents and soaps must be extensively filtered prior to disposal. The replacement of spent detergents and soaps and the filtration of the waste wash water render the aqueous parts washers very costly to operate. Therefore, the cost of such cleaning systems has proven to be excessive, even though the aqueous based systems are not entirely effective.

## SUMMARY OF THE INVENTION

It has therefore been an objective of this invention to provide an improved apparatus and system for cleaning contaminants, particularly dye-based penetrants, wax, and machining oil, from industrial parts, especially those which have intricate orifices and internal passages.

It has been a further objective of this invention to provide such a cleaning device and system which is environmentally safe.

Another objective of the invention has been to provide such a device and system to effectively clean and remove the contaminants from the parts in a cost effective and time efficient manner, including the recycling of wash water used in the cleaning operation.

These objectives have been attained by a cleaning system based upon the injection of pressurized and superheated water into a wash cabinet containing the parts. The water is released through a pattern of nozzles distributed within the wash cabinet. The nozzles include fan-type nozzles which are adapted for wide dispersion of the superheated water for cleaning the external surfaces of the industrial parts. Additionally, specially designed stepped expansion nozzles within the wash cabinet are adapted for cleaning the intricate orifices and internal passages of the complex geometry parts. As the water exits the expansion nozzles, a portion of it flashes to steam and this controlled vaporization creates high velocity superheated water droplets impinging upon the parts. The result is an invasive, high temperature cleaning action which does not require the addition of chemicals or detergents.

The major components of this invention include a wash cabinet with a cleaning compartment containing a rotating motorized turntable rack onto which the parts are mounted for cleaning. Separate and remote steam generation and filtration systems are configured in a closed loop with the wash cabinet for recycling the water after being used in cleaning the parts. The closed loop configuration of this invention minimizes the overall system operational cost by reducing the fuel requirements to heat the water to the elevated temperature.

The process of cleaning according to this invention includes a four-stage cycle including preheat, wash, cool down, and drying stages. After the parts are loaded into the specially designed basket or rack within the cleaning compartment of the wash cabinet, a door is secured closed thereby sealing the wash cabinet as a closed chamber. The system is then activated to begin the preheat stage of the cycle during which a modulating burner within the steam generator operates to raise the temperature of a supply of water to a superheated temperature, typically over 310° F. The water is maintained at a pressure over 100 PSI to ensure that it remains in the liquid state when superheated.

The steam generator operates as an on-demand unit with energy expended only when in actual operation to thereby reduce the fuel requirements and operating cost of the system in comparison to other cleaning systems which constantly maintain a reservoir of heated water. With this invention, the steam generator only operates on-demand during the preheat and wash stages of the cleaning cycle to minimize fuel costs.

Once the wash temperature is achieved, the superheated water is released into the cleaning compartment of the wash cabinet through a series of nozzles, including a combination of fan nozzles and specially designed stepped expansion nozzles. The stepped expansion nozzle is an important element of this invention to clean the complex geometry parts in that the nozzle both directs the water

and enables it to accelerate upon exiting a restricted opening of the nozzle. The fan nozzles disperse the superheated water in a broader pattern and are primarily intended to clean the external surfaces of the parts.

The superheated water is delivered to the nozzles at a temperature above 310° F. and must be pressurized in order to prevent the superheated water from boiling or vaporizing into steam. The superheated water is pressurized to over 100 PSI and is forced through the restrictive opening in either of the two preferred types of nozzles. The cleaning compartment of the wash cabinet remains at ambient pressure; therefore, once the water exits the restrictive opening of the nozzle, it is no longer subjected to the pressurization.

Upon exiting the restrictive opening of the stepped expansion nozzle and entering the unpressurized cleaning compartment, a portion of the water cools by vaporizing. Typically, from 5 to 15% of the superheated water by volume flashes to vapor upon exiting the restrictive opening of the nozzle and entering the ambient pressure cleaning compartment.

The water which flashes to steam vapor propels the remaining volume of superheated water to an increased velocity after exiting the restrictive opening and passing through the stepped expansion portion of the nozzle. Unlike the standard pressure washer or fan nozzle where the restrictive opening is the last component the water passes through before reaching the part to be cleaned, the stepped

expansion nozzle provides for the acceleration of the superheated water and directs the accelerated water toward the parts rather than allowing it to dissipate in all directions.

The expansion or vaporization of a portion of the superheated water within the stepped expansion nozzle increases the velocity of the remaining superheated water impinging upon the contaminated parts to thereby enhance the cleaning of the parts. As a result, the parts are not actually cleaned by vaporized water or steam, according to this invention, but the superheated water remaining in the liquid state is accelerated by portions of water vaporized to steam thereby creating significant kinetic energy for the water to impact upon the contaminated parts for the cleaning thereof.

Typically the wash stage lasts for 5-10 minutes after which the cleaning system of this invention proceeds to the cool down stage. In the cool down stage, the burner of the steam generator is turned off and the water collected in the wash cabinet is re-circulated within the system for typically 3-4 minutes to cool the water lines, wash cabinet, cleaning compartment, and cleaned parts. An exhaust fan is activated during the cool down stage to evacuate any accumulated vapor in the cleaning compartment of the wash cabinet.

The final step of the cleaning system of this invention is the drying stage. While the exhaust fan continues to cool the cleaning compartment and the wash cabinet; the parts will tend to flash dry from the retained heat delivered to them from the superheated water.

An air knife projects into the cleaning compartment to disburse and circulate air thereby enhancing the drying process. Other drying systems can be employed as a substitute for or in addition to the air knife. Typically, the drying stage continues for 2-3 minutes, after which the cleaning cabinet can be opened and the cleaned industrial parts removed free of contaminants.

Also included in this invention is a two filter cartridge system in line within the closed loop water recycling system between the wash cabinet and the steam generator. After the water is sprayed onto the contaminated parts, it is collected in the bottom of the wash cabinet in a basin. The collected water is then fed through a return tube to a filtering system including both a standard particulate filter to remove any large particles from the water and an oil absorbing filter. Other filtration systems can be used with this invention which are appropriate for the removal of the contaminants in the wash water. Specifically, oil skimmers and oil absorption systems can be included with this invention.

As a result of the cleaning system and apparatus of this invention, contaminants, including oil-based dye penetrants, waxes and machining oils, can be efficiently and effectively cleaned from industrial parts, especially those having complex geometries, intricate orifices and internal passages. Furthermore, the cleaning is accomplished in a timely and cost effective manner without the use of toxic chemicals and detergents by the utilization of superheated

water which can be recycled within the system for an environmentally sound industrial cleaning application.

## BRIEF DESCRIPTION OF THE DRAWINGS

The objectives and features of this invention will become more readily apparent with the following detailed description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic representation of the industrial parts cleaning system of this invention including a wash cabinet;

Fig. 2 is a cross-sectional top view of the wash cabinet;

Fig. 3 is a cross-sectional view of a stepped expansion nozzle; and

Fig. 4 is a perspective view of a typical industrial part to be cleaned with this invention.

## DETAILED DESCRIPTION OF THE INVENTION

A system 10 for cleaning industrial parts according to this invention is shown in Fig. 1. The system 10 includes a steam generator 12 with a feed pipe 14 for delivering water heated in the steam generator 12 to a wash cabinet 16 containing contaminated industrial parts to be cleaned by spraying the superheated water onto the parts. After the superheated water is sprayed onto the parts, it is fed through a filter 18 to remove any contaminants or impurities thereon prior to recycling the water back to the steam generator 12 through a return pipe 20.

The steam generator 12 is capable of heating water supplied to it through a water inlet valve 22 to a temperature in the range of 310° to 360° F. The water is preferably delivered to the wash cabinet 16 at a temperature of 325°. A 750,000 BTU natural draft self-modulating gas burner (not shown) with thermostat control is preferably provided in the steam generator 12 for heating the water. The steam generator 12 operates as an on-demand unit so as to only heat the water as required by the system, thereby conserving energy operating costs by not continually heating the water when the system 10 is not in operation. The self-modulating gas burner further reduces heating requirements by adjusting to the incoming water temperature to superheat the water. The water input to the steam generator 12 comes from the water supply at ambient temperature and from recycled water which has previously been heated and therefore requires less heat input and fuel to achieve the required 325°. As a result, the self modulating burner is more fuel efficient and less costly to operate.

The superheated water must be pressurized to approximately 100-150 PSI in order to prevent it from vaporizing to steam at the elevated temperature. Preferably, a 10 gallon per minute diaphragm pump (not shown) with a 3 horse power electric motor (not shown) is provided with the steam generator 12 in order to pressurize the superheated water and pump it to the wash cabinet 16. A stainless steel control panel (not shown) is provided on the steam generator 12

to include visual function indicators such as pressure, flow, and temperature displays to facilitate the operation of the steam generator 12.

The feed and return pipes 14, 20, in addition to any internal piping within the wash cabinet 16 and the steam generator 12, are preferably constructed of stainless steel in order to prevent rust and degradation and to extend the useful life of the system 10.

The filter 18, positioned in the closed loop system of this invention between the wash cabinet 16 and the steam generator 12, cleans and recycles the water after exiting the wash cabinet 16. The filter 18 is preferably a two stage system including a simple particulate filter to remove any large particles from the waste water and a dual cartridge oil absorbing filter. The oil absorbing filter has preferably a 6 gallon per minute flow rate capability and up to 3 gallons of oil absorption capacity and is equipped with a built-in pressure gauge, such as the Filterdyne Xilox II oil absorbing filter.

The supply water input to the system 10 through the steam generator 12 preferably has a hardness within the 4 to 8 grains range for acceptable system performance. Otherwise, a water softener (not shown) is required for treating the water input into the system 10. With the recycling capability of the industrial parts cleaning system 10 of this invention, a minimal amount of the water will be lost through evaporation during a typical cleaning cycle. However, an

optional condenser (not shown) can be included with the system 10 which recoups virtually all of the steam lost in the cleaning process.

The wash cabinet 16 of this invention is shown in Figs. 1 and 2 including a cleaning compartment 24 in which contaminated industrial parts are cleaned with superheated pressurized water supplied to the wash cabinet 16 through the feed pipe 14 from the steam generator 12. The contaminated parts to be cleaned are mounted in a generally circular rotating basket 26 constructed of wire mesh or otherwise perforate stainless steel. The turntable-style basket 26 is mounted on a central longitudinal shaft 28 which is rotationally driven by a motor 30 supported on a shelf 29 secured to the rear exterior wall of the wash cabinet 16. The basket 26 is driven at an approximate constant rotational velocity by the shaft 28 coupled to the motor 30. A drive shaft 31 of the motor 30 is coupled to a gear box 33 which in the preferred embodiment of this invention has a 2:1 gear ratio reduction. A gear box output shaft 35 extends horizontally from the gear box 33 and through the rear wall of the wash cabinet 16 to a second gear box 39 to drive the longitudinal shaft 28. The gear box output shaft 35 extends concentrically within a tube 37, preferably constructed of stainless steel, in order to protect the shaft 37 within the cleaning compartment 24.

The basket 26 is maintained at a specified height on the longitudinal drive shaft 28 by an upper and lower collar 32, 34 encircling the longitudinal drive shaft 28. Each collar 32, 34 is

secured to the longitudinal drive shaft 28 by a set screw 36. In the preferred embodiment of this invention, the basket 26 can be longitudinally positioned within a 6 inch range on the shaft 28 by repositioning the lower and upper collars 32, 34. It is preferable to have the basket 26 positioned on the shaft 28 for optimum cleaning so that the parts within the basket 26 are approximately 6-8 inches from the nozzles.

Although a wide variety of parts can be cleaned with this invention, this system is uniquely designed for the cleaning of metallic industrial parts which include a number of intricate orifices, openings, and passageways as shown by an exemplary part 38 in Fig. 4 and disclosed in U.S. Patent Nos. 4,762,464 and 4,808,785. This invention is particularly useful for the removal of machining oil, oil based dyes/penetrants, wax, and other contaminants which can accumulate or clog multiple openings 40 within the complex parts 38. For example, this system 10 has proven to be particularly effective in cleaning RC77 fluorescent penetrant, white mineral oil, and vegetable wax from such parts 38. These contaminants are commonly employed in the manufacture, machining, and inspection of the parts 38.

The wash cabinet 16 as seen in Figs. 1 and 2, includes the rotationally driven turntable-style basket 26 which is preferably about 36 inches in diameter, and a number of nozzles 42 which are attached to a stainless steel pipe 44 within the wash cabinet 16. The

nozzles 42 and stainless steel pipe 44 are interconnected to the feed pipe 14 through an inlet 46 on the back side of the wash cabinet 16 to supply the superheated pressurized water to the cleaning compartment 24. Walls 48 of the wash cabinet 16 are preferably one inch thick with a layer of insulation 50 sandwiched between an inner and outer stainless steel panel 52, 54. The insulation 50 is included as a sound deadening component to lessen the noise generated during the cleaning of the contaminated parts 38 and also to reduce heat loss from the superheated water sprayed onto the contaminated parts 38 in the cleaning compartment 24.

A wide access door 56 is pivotally attached to the wash cabinet 16 by hinges 58 to provide access to the turntable basket 26 for the loading and unloading of the parts 38 (Fig. 2). A safety latch 60 secures the door 56 closed during the cleaning cycle. A seal 59 is provided to ensure tight enclosure between the door 56 and the wash cabinet 16. Preferably, the mechanical safety latch 60 prevents an operator from accidentally opening the door 56 during a cleaning cycle.

A stainless steel control box 62 with function indicator lights (not shown) including a solid state programmable controller is mounted on the wash cabinet 16 for the operation of the system 10. After the superheated water has been sprayed through the nozzles 42 onto the contaminated parts 38, it is collected in a basin 64 in the lower portion of the wash cabinet 16. Preferably, the basin 64 has

a capacity of approximately 100 gallons and is constructed of stainless steel. The water collected in the basin 64 exits the wash cabinet 16 through an outlet 66 which is connected to the return pipe 20 leading to the filter 18 for the recycling of the waste water.

As shown in Figs. 1 and 2, seven nozzles 42 are positioned within the cleaning compartment 24 in the preferred embodiment of this invention. However, it will be appreciated by one of ordinary skill in the art that this invention is not limited by the specific configuration, placement, or number of nozzles shown in this preferred embodiment. This invention may include a stepped expansion nozzle 42 as shown in Fig. 3 which is specially designed for the cleaning applications of this invention. Other more standard nozzles can be included in this system 10 which are well known in the art, such as fan-type nozzles. The supply side of the stepped expansion nozzle 42 is connected to a nozzle inlet pipe 68, preferably a 0.5 inch diameter stainless steel pipe. The nozzle inlet pipe 68 feeds the water to a restrictive orifice 70 within a flanged bushing 72 in the nozzle 42. The orifice 70 is preferably 0.098 inches in diameter and leads to a 5/16 inch diameter nozzle entrance 74. The diameter of the nozzle 42 is then increased in a series of steps 76 over a four inch length to an outlet 78 diameter of 5/8 inch.

The superheated liquid water delivered to the stepped expansion nozzle 42 is preferably 325° F., but within a range of 310° F. and 360° F. and at a pressure of 100-150 PSI. The specially

designed nozzle 42 for this system converts the enthalpy of the superheated water to kinetic energy to thereby increase the velocity at which the superheated water impinges upon the contaminated parts 38. This is accomplished by decreasing the pressure of the water within the nozzle 42 through the series of stepped expansions.

As the water passes from the nozzle inlet pipe 68 through the orifice 70 to the nozzle entrance 74, there is a significant pressure drop during which a portion of the superheated water vaporizes to steam. The cleaning compartment 24 and steps 76 of the nozzle 42 are maintained at ambient pressure. Therefore, after the superheated pressurized water exits the orifice 70, it experiences a drastic decrease in pressure below the saturated pressure point of steam, thereby vaporizing a portion of the superheated water to steam.

When the water passes through the orifice 70, it is no longer subjected to the additional pressurization and cannot remain a liquid at the elevated temperature. The water cools itself to approximately 212° F. by vaporizing a portion of its volume. Approximately 15% of the superheated water flashes to steam thereby cooling the remaining liquid water within the nozzle 42. The nozzle 42 of this invention directs and adds velocity to the water droplets to thereby increase the velocity with which they impinge upon the contaminated parts 38. The steam vapor propels the remaining water within the nozzle 42 by the release of kinetic energy. For optimal cleaning, the nozzles 42 of this invention should be positioned approximately 6-8 inches from the

contaminated parts 38. The preferred embodiment of this system 10 is designed to deliver approximately five gallons of superheated water and steam per minute distributed over the seven nozzles 42 within the cleaning compartment 24. The fan nozzles may be included in the nozzle configuration of this invention and are more adapted for the cleaning of the external surfaces of the parts 38.

A typical cleaning cycle of this invention includes four stages: preheat, wash, cool down, and drying. To begin a cycle, an operator loads the parts 38 into the specially designed turntable style basket 26 and closes and secures the door 56 on the wash cabinet 16. The required cleaning time is selected on the wash timer and the start button on the control panel (not shown) is actuated to begin the cleaning cycle. The system 10 then proceeds automatically through the completion of the four stage wash cycle. During the preheat stage, the modulating burner operates to raise the water temperature to preferably 325° F. for delivery to the cleaning compartment 24. Under normal operating conditions, the preheat stage will take approximately 2-4 minutes, even after several hours of inactivity. The modulating steam generator operates on demand with energy expended only when in actual operation to thereby minimize operating costs and fuel requirements.

After the critical temperature of 325° F. is achieved, the wash stage begins and the parts 38 are rotated through the pattern of nozzles 42 within the cleaning compartment 24 by the rotationally

driven shaft 28 and turntable-style basket 26. A typical wash stage lasts for 5-10 minutes. After the wash stage, the system proceeds to a cool down stage during which the burner is shut down and the water is recirculated for approximately 3-4 minutes for cooling within the pipes, wash cabinet, and parts. A high speed exhaust fan (not shown) can be included for evacuating any accumulated vapor within the cleaning compartment 24 of the wash cabinet 16 during the cool down stage.

After the cool down stage, the final stage of the cleaning cycle is drying. While the exhaust fan (not shown) continues to cool the wash cabinet 16 and cleaning compartment 24, the parts 38 will tend to flash dry from the retained heat transferred to them from the superheated water. An air knife or other appropriate air circulation system (not shown) can be coupled to the wash cabinet 16 to enhance the drying process by circulating forced air therein. A typical air knife compatible with this system 10 is an 18 inch air knife manufactured by Exair which is solenoid activated to operate off of house air supply. The drying stage typically lasts 2-3 minutes after which the cycle is complete and a ready light on the control panel indicates that the wash cabinet 16 can be opened to remove the cleaned parts 38.

From the above disclosure of the general principles of the present invention and the preceding detailed description of a preferred embodiment, those skilled in the art will readily comprehend the

various modifications to which the present invention is susceptible. Therefore, we desire to be limited only by the scope of the following claims and equivalents thereof.

We claim:

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Claims:

1. An apparatus for cleaning a work piece, the apparatus comprising:

a wash cabinet having an enclosed cleaning compartment;

a rack for holding the work piece, said rack being mounted within said cleaning compartment of said wash cabinet;

a plurality of nozzles mounted within said cleaning compartment and directed toward the work piece;

means for heating a supply of water to a temperature above approximately 310° F.;

means for delivering said heated water supply to said nozzles, said heated water supply being forced through said nozzles and applied to the work piece to thereby clean the work piece; and

wherein said nozzles are stepped expansion nozzles so that when said heated water supply is forced through said stepped expansion nozzles a portion of said heated water vaporizes to steam to thereby release kinetic energy and increase the velocity of said heated water supply exiting said stepped expansion nozzles.

2. The apparatus of claim 1 wherein said water supply is heated and delivered to said nozzles at a pressure above approximately 100 psi to thereby maintain said heated water supply in a liquid state.

3. The apparatus of claim 1 further comprising:

means for recycling said water supply for re-use in the cleaning of other work pieces after it has been applied to the work piece through said nozzles, said recycling means including at least one filter through which said water supply is processed prior to returning to said heating means.

4. The apparatus of claim 1 further comprising:

an exhaust fan mounted to said wash cabinet, said exhaust fan being capable of evacuating accumulated vapor within said cleaning compartment.

5. The apparatus of claim 1 further comprising:

an air knife mounted in said cleaning compartment of said wash cabinet, said air knife being operably connected to a supply of pressurized air and upon actuation said air knife disperses said pressurized air supply within said cleaning compartment in order to dry the work piece.

6. The apparatus of claim 1 wherein said heating means comprises a steam generator.

7. The apparatus of claim 1 wherein said delivering means comprises a plurality of interconnected pipes joining said wash cabinet and said heating means into a closed loop system.

8. A method for cleaning an airfoil or another like work piece having small intricate orifices therein, the method comprising the steps of:

placing the work piece in a cleaning compartment of a wash cabinet;

pressurizing a supply of water to above approximately 100 psi;

heating said pressurized water supply to a temperature above approximately 310° F.;

delivering said pressurized and heated water supply to a plurality of nozzles within said cleaning compartment;

spraying said pressurized and heated water supply onto the work piece through said nozzles to thereby clean the work piece, a portion of said pressurized and heated water supply vaporizing to steam during said spraying to thereby release kinetic energy and increase the velocity of the remainder of said pressurized and heated water supply during said spraying.

9. The method of claim 8 further comprising:

collecting said water supply after said spraying;

filtering said collected water;

recycling said filtered water to be re-heated for subsequent cleaning operations.

10. The method of claim 8 further comprising:

rinsing the work piece within said wash cabinet with water after said spraying to thereby cool the work piece and said wash cabinet.

11. The method of claim 8 further comprising:

evacuating any accumulated vapor within said wash cabinet after said spraying with an exhaust fan operatively connected to said wash cabinet.

12. The method of claim 8 further comprising:

drying the work piece within said cleaning compartment after said spraying step.

13. The method of claim 8 further comprising:

drying the work piece by circulating air within said cleaning compartment with an air knife.

14. A method for cleaning dye penetrant from a work piece contaminated with the dye penetrant, the method comprising the steps of:

placing the work piece in a cleaning compartment of a wash cabinet;

pressurizing a supply of water to above approximately 100 psi;

heating said pressurized water supply to a temperature above approximately 310° F.;

delivering said pressurized and heated water supply to a plurality of nozzles within said cleaning compartment;

spraying said pressurized and heated water supply onto the work piece through said nozzles to thereby clean the work piece by removing the dye penetrant therefrom, a portion of said pressurized and heated water supply vaporizing to steam during said spraying to thereby release kinetic energy and increase the velocity of the remainder of said pressurized and heated water supply during said spraying.

15. The method of claim 14 further comprising:

collecting said water supply after said spraying;

filtering said collected water;

recycling said filtered water to be re-heated for subsequent cleaning operations.

16. The method of claim 14 further comprising:

rinsing the work piece within said wash cabinet with water after said spraying to thereby cool the work piece and said wash cabinet.

17. The method of claim 14 further comprising:

evacuating any accumulated vapor within said wash cabinet after said spraying with an exhaust fan operatively connected to said wash cabinet.

18. The method of claim 14 further comprising:

drying the work piece within said cleaning compartment after said spraying step.

19. The method of claim 14 further comprising:

drying the work piece by circulating air within said cleaning compartment with an air knife.

20. A method for cleaning a work piece having wax contained in small orifices thereof, the method comprising the steps of:

placing the work piece in a cleaning compartment of a wash cabinet;

pressurizing a supply of water to above approximately 100 psi;

heating said pressurized water supply to a temperature above approximately 310° F.;

delivering said pressurized and heated water supply to a plurality of nozzles within said cleaning compartment;

spraying said pressurized and heated water supply onto the work piece through said nozzles to thereby clean the work piece by removing the wax therefrom, a portion of said pressurized and heated water supply vaporizing to steam during said spraying to thereby release kinetic energy and increase the velocity of the remainder of said pressurized and heated water supply during said spraying.

21. The method of claim 20 further comprising:

collecting said water supply after said spraying;

filtering said collected water;

recycling said filtered water to be re-heated for subsequent cleaning operations.

22. The method of claim 20 further comprising:

rinsing the work piece within said wash cabinet with water after said spraying to thereby cool the work piece and said wash cabinet.

23. The method of claim 20 further comprising:

evacuating any accumulated vapor within said wash cabinet after said spraying with an exhaust fan operatively connected to said wash cabinet.

24. The method of claim 20 further comprising:

drying the work piece within said cleaning compartment after said spraying step.

25. The method of claim 20 further comprising:

drying the work piece by circulating air within said cleaning compartment with an air knife.

26. A method for cleaning an airfoil or another like work piece having small intricate orifices therein, the method comprising the steps of:

mounting the work piece within a cleaning compartment of a wash cabinet;

pressurizing a supply of water to above approximately 100 psi;

heating said pressurized water supply to a temperature above approximately 310°F;

delivering said pressurized and heated water supply to the work piece within said cleaning compartment;

spraying said pressurized and heated water supply through the work piece mounted within said cleaning compartment to clean the work piece, a portion of said pressurized and heated water supply vaporizing to steam during said spraying to thereby release kinetic energy and increase the velocity of the remainder of said pressurized and heated water supply during said spraying.

27. The method of claim 26 further comprising:

collecting said water supply after said spraying;

filtering said collected water;

recycling said filtered water to be re-heated for subsequent cleaning operations.

28. The method of claim 26 further comprising:

rinsing the work piece within said wash cabinet with water after said spraying to thereby cool the work piece and said wash cabinet.

29. The method of claim 26 further comprising:

evacuating any accumulated vapor within said wash cabinet after said spraying with an exhaust fan operatively connected to said wash cabinet.

30. The method of claim 26 further comprising:

drying the work piece within said cleaning compartment after said spraying step.

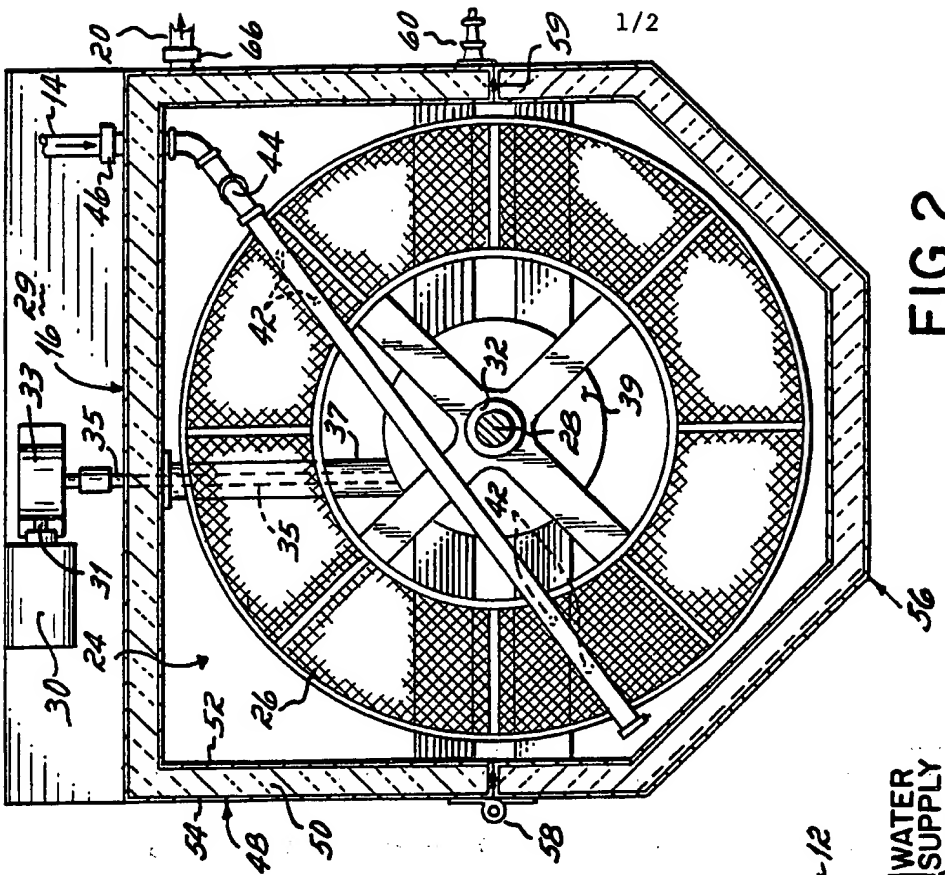

FIG. 2

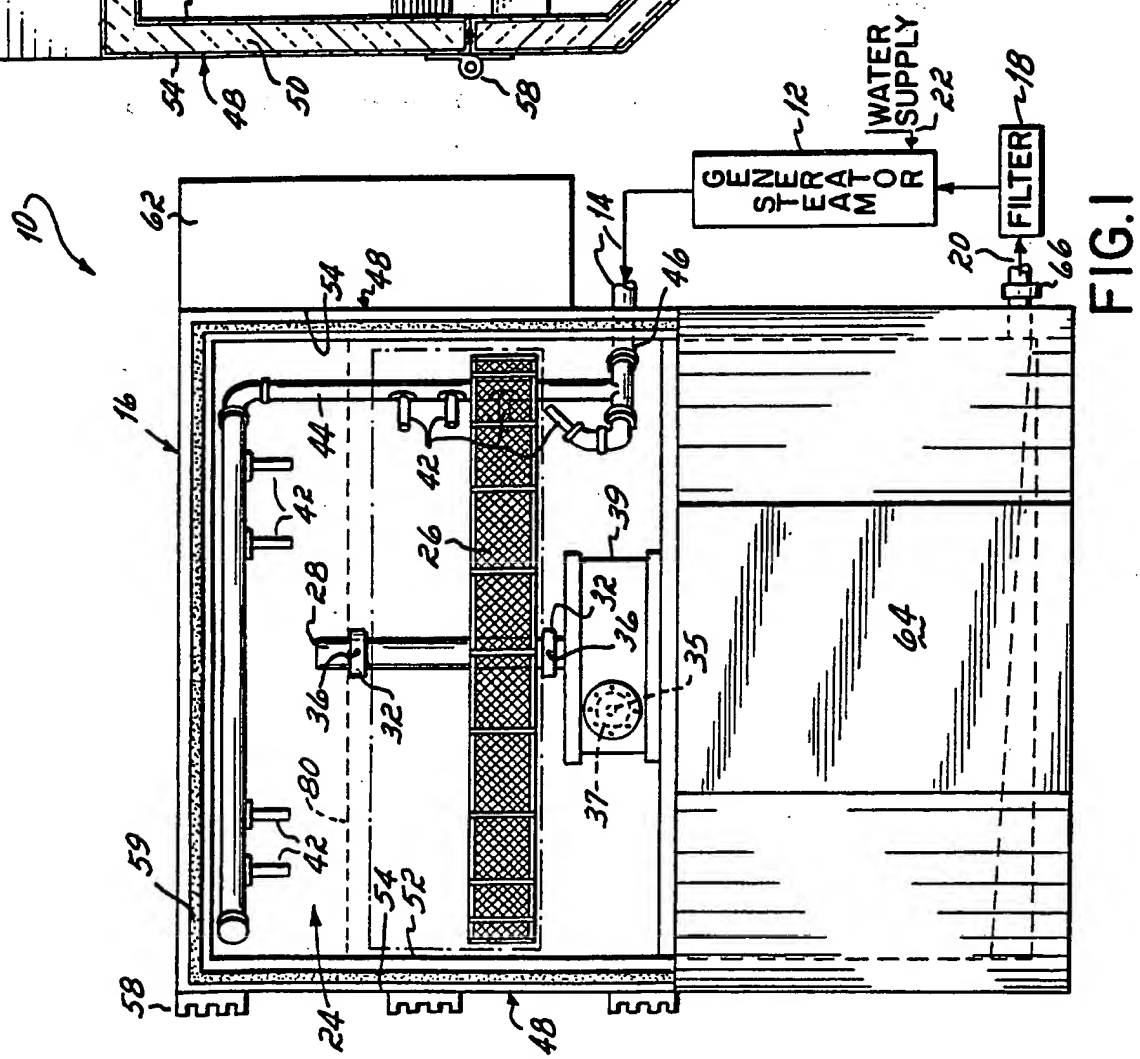


FIG. 1

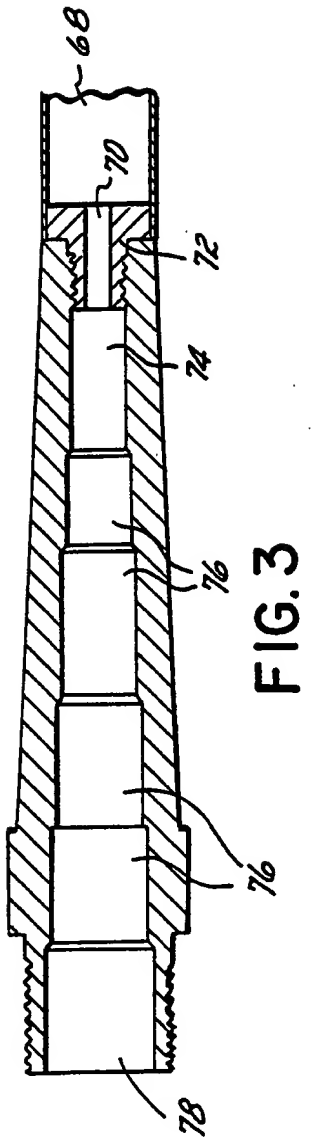


FIG. 3

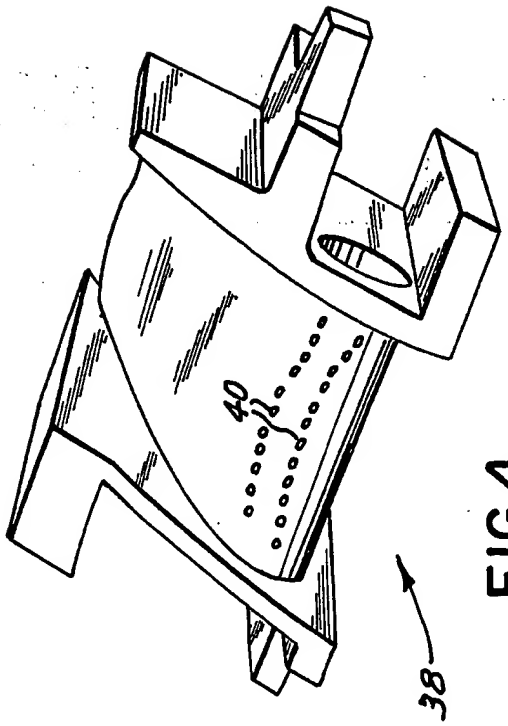


FIG. 4

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07790

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :B08B 3/02, 3/10, 7/04
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 134/10, 11, 21, 22.12, 22.18, 25.4, 30, 35, 95.2, 95.3, 105, 108, 111; 34/443, 475, 485, 493, 497; 239/589, 590

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US, A, 2,546,385 (CHRISTINA) 27 MARCH 1951, CLAIMS AND FIGURE 1. | 1,5,7-8,12-14, 18-20, 24-26, 29-30 |
| Y | US, A, 2,919,070 (ARANT) 29 DECEMBER 1959, CLAIMS AND FIGURES 1 AND 2. | 1,2,6,8,10, 14,16,20,22,26,28 |
| Y | US, A, 3,624,750 (PETERSON) 30 NOVEMBER 1971, CLAIMS. | 3,9,15,21, 27 |
| Y | US, A, 3,113,046 (REDDICK ET AL) 03 DECEMBER 1963, FIGURE 1 AND CLAIMS. | 1,3,4,7 |
| Y | US, A, 4,439,241 (AULT ET AL), 27 MARCH 1984, ABSTRACT AND CLAIMS. | 8,14,20,26 |

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

| | | | |
|---|---|---|---|
| * | Special categories of cited documents: | "T" | later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| "A" | document defining the general state of the art which is not considered to be of particular relevance | "X" | document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone |
| "E" | earlier document published on or after the international filing date | "Y" | document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| "L" | document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | "&" | document member of the same patent family |
| "O" | document referring to an oral disclosure, use, exhibition or other means | | |
| "P" | document published prior to the international filing date but later than the priority date claimed | | |

| | |
|---|---|
| Date of the actual completion of the international search<br>25 OCTOBER 1994 | Date of mailing of the international search report<br>NOV 02 1994 |
| Name and mailing address of the ISA/US<br>Commissioner of Patents and Trademarks<br>Box PCT<br>Washington, D.C. 20231<br>Facsimile No. (703) 305-3230 | Authorized officer<br>SAEED T. CHAUDHRY<br>Telephone No. (703) 308-3319 |

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07790

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US, A, 4,565,583 (VENETTA) 21 JANUARY 1986, ABSTRACT AND CLAIMS. | 8,14,20,26 |
| Y | US, A, 5,054,692 (FOSTER ET AL) 08 OCTOBER 1991, FIGURE 1. | 1 |
| Y | US, A, 5,118,357 (SABATKA) 02 JUNE 1992, ABSTRACT AND CLAIMS. | 5,13,19,25, 30 |
| Y | US, A, 5,120,370 (MORI ET AL) 09 JUNE 1992, FIGURE 1 AND CLAIMS. | 1,3,6-9,14, 15,20,21, 26-27 |
| Y | SU, 902-839 (ROSPROMKLKHOZPROEK) 07 FEBRUARY 1982, ABSTRACT AND FIGURE. | 1 |
| A | US, A, 2,277,291 (BLAIR) 24 MARCH 1942. | |
| A | US, A, 4,079,522 (HAM) 21 MARCH 1978. | |

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/07790

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

134/10, 11, 21, 22.12, 22.18, 25.4, 30, 35, 95.2, 95 3. 105. 108, 111; 34/443, 475, 485, 493, 497; 239/589, 590